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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

In Task I, the ~~Experimental~~ research ~~for this two-year period~~ primarily involved refinement of the experimental apparatus, ~~the~~ instrumentation, ~~and the~~ measurement techniques, ~~in~~ the first year and acquisition of experimental data. ~~In~~ the second year. Special efforts were made to assure the reliability of the measurements, including runs made to examine the process of oxide formation when utilizing pure nickel surfaces. Experimental data were acquired for both liquid kerosine (Jet-A) and gaseous commercial propane fuels over a broad range of run conditions. Evaluation of the results in the context of existing theories and modifications of the CONCHAS-SPRAY code to model this experimental system were also undertaken, in the report period.

In Task II, ~~during~~ the ~~first year~~ the extensive experimental results on blowoff velocity, obtained using both conventional Vee-gutter and single-sided flameholders, provided the data base for an analytical study of the factors governing the stability characteristics of bluff-body flameholders. An equation was derived for predicting b.....

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blowoff velocity in terms of flameholder size, flameholder blockage, ambient air pressure and temperature, and laminar flame speed Predictions of blowoff velocity based on this equation showed excellent agreement with ~~the~~ experimental values , In Task-II obtained in this investigation and with the published results of other workers. The measurements of blowoff velocity obtained in the second year for both gaseous and liquid fuels, generally confirmed theoretical predictions in regard to the dependence of peak blowoff velocity on laminar flame speed. They also showed that gas turbine fuels in the range from Jet A to diesel oil (DF2) exhibit very similar flameholding characteristics, since their laminar flame speeds are virtually the same.

In Task III, during the first year of effort, experimental studies ~~have been~~ were completed and results correlated for ventilation flow from surroundings into a cavity with a small internal flow. ~~During the~~ second year of effort, extensive flow visualization studies ~~have been~~ undertaken for flow past a protrusion, including the case of a jet through the protrusion. These studies ~~have~~ provided data on formation of vortices adjoining and over the protruberance and the nature of jet flow entrainment into them. Based on an analytical model for low speed flow past a protruberance, the flow field in the vicinity of the protrusion has been computed While the flow field downstream of the protrusion is predicted satisfactorily, further developments are needed in order to predict the upstream flow field. The test rig for combustion studies is nearing completion.

TASK I

AFOSR-TR- 86-0874

BIANNUAL REPORT

AFOSR-82-0107

Period November 15, 1981 to November 14, 1983

TASK I

IGNITION OF FUEL SPRAYS BY HOT SURFACES

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TECHNICAL OBJECTIVE

Acquisition of experimental data for heated boundary-layer flows of fuel spray/air mixtures under conditions leading to ignition of the mixture; the data are to be of sufficient detail and are to be taken over a sufficient range of flow and spray parameters to enable the development of theoretical models for ignition which can be used in aircraft fire hazard prediction.

APPROACH

An experimental facility has been developed in which each of the pertinent parameters of the problem can be independently controlled (boundary layer properties, mean droplet size, fraction of fuel vaporized, wall conditions, etc.). Optical measurements (LDV, scattering, image-type spray analysis) and sampling probe measurements are made both upstream and downstream of the heated length of duct serving as the test section to obtain the flow properties in the boundary layer. Those data will serve as a basis for the development of theoretical analyses of the processes. Both ignition correlations and a more detailed boundary layer analysis are to be developed in the investigation.

PROGRESS

In the first year of the period covered by this report, most of the efforts were devoted to refining the measurement methods and experimental procedures to obtain reliable local measurements of the two-phase boundary layer flow properties to more closely

relate the ignition phenomena to the relevant physical properties of the flow. To that end, substantial efforts were devoted to tailoring the flow profiles and to evaluation and refining of the individual measurements involved. Runs made with the complete system initially revealed several minor changes would be necessary in the instrumenta- tion for reliable operation. For example, it was found to be essential to install a controller for the electrically-heated catalytic combustor in the probe/sampling system to extend its operational lifetime for the range of operating conditions needed and the run procedures adopted. Because of the sensitivity of one of the sampling methods used for determining the fraction of fuel vaporized, it was found to be critical to assess the isokinetic sampling condition accurately. A procedure employing LDA measuremnts was developed and refined for that purpose. More accurate wall temperature measurements were also introduced, and better uniformity of the wall temperature was achieved by improving thermal contacts and by monitoring and controlling the sheath temperatures of the electrical heater elements.

Runs were made over a broad range of parameters to explore the nature of the data and the ignition process. The boundary layer was determined to be composed of a vapor/fuel mixture for most of the runs made under conditions leading to ignition, covering a range of bulk equivalence ratios from 0.2 to 2.5. Average droplet sizes for those runs were varied from below 10 microns to about 50 microns. Significant transport of fuel

toward the wall was observed, presumably due mostly to droplet motion. The observed wall tempera- ture at ignition was found to exhibit the usual minimum for bulk flow condi- tions with equivalence ratios near unity. Runs were made with both pure nickel and stainless steel surfaces. Those made with pure nickel exhibited rather erratic behavior due to the formation of an substantial oxide layer, primarily under fuel-rich operating conditions.

Two papers relating to the small injectors and the spray measurement system were presented at the ICLASS '82 meeting in Madison, WI, in the summer of 1982. One M.S. Thesis dealing with the LDA measurements was also completed.

In the second year of the period covered by this report, most of the experimental research was concerned with the acquisition of data for kerosine (Jet-A) fuel sprays and for a gaseous fuel (commercial propane). Both nickel and stainless steel surfaces were employed for those runs. Effects of free- stream velocity, boundary layer profile, bulk equivalence ratio, and inlet air temperature were examined. A number of supplemental tests were made to check what appeared to be anomolous data under some run conditions, or to examine certain conditions which might have led to facility-related results. Most of the questions raised were resolved satisfactorily, thereby improving the reliability of the information acquired and refining the operation of the facility.

Further insight was acquired as to the problems encountered with the pure nickel surface, including a chemical analysis of the oxide layer and direct observations of the nature of the ignition in the vicinity of a flaking oxide layer. It was judged to be virtually impossible to obtain data represen- tative of strictly clean nickel surfaces under fuel-rich operating conditions. Such measurements would probably have to be made under more rapid heating rates than were possible with the existing apparatus. The details of the role played by the oxide layer in the ignition process, apart from its role as a thermal barrier, remained unclear.

The runs made with propane gas were intended to simulate a situation corresponding to a bulk mixture of kerosine vapor and air. Those runs showed the important influence of the initial boundary layer profile on the wall temp- erature at ignition, yielding lower wall temperatures at ignition for a thicker initial boundary layer. Runs were made over the range of flammability limits for the mixture.

Along with the experimental investigations conducted in this research, efforts were made to compare the results with existing theories, such as that of T.Y. Toong and others, and to initiate necessary modifications of the CONCHAS-SPRAY code to render it useful in describing the boundary layer flows of concern here.

TECHNICAL SIGNIFICANCE/RELEVANCE

Means for predicting aircraft fire hazards require relaible theoretical models for the conditions leading to ignition of fuel/air mixtures of many types and under a broad range of conditions. The necessary data on which to base such theories must be acquired in experimental research programs of the type described here. The development of the imaging-type spray analysis system for measuring local properties of sprays (number density, size distribution function) should find applications in a range of industrial processes involving sprays, as well as for fuel preparation in gas turbines and other engines. The method has been developed partly under the AFOSR program and partly under NASA sponsorship. The miniature airblast injectors developed for this program have been found to be exceptionally efficient (a ratio of gas to liquid flow rates of 0.02 as compared to 2.0 for more conventional injectors). These could find applications both for fuel preparation and in certain industrial processes where gas/liquid injection is acceptable and where the efficiency is important (possibly even in reciproca- ting engines).

EXPRESSIONS ON INTEREST

A number of researchers have inquired as to the methods employed in this investigation, particularly those related to the use of the microscopic airblast atomizers.

PUBLICATIONS

1. Skifstad, J.G., "An Automated Imaging-Type Spray Analysis System for Local Spray Properties" presented at the ICLASS-82 meeting in Madison, WI, 1982.

2. Skifstad, J.G., "Microscopic Airblast Atomizers" presented at the ICLASS-82 meeting in Madison, WI, 1982.

3. Skifstad, J.G., "Representation of Functions by Gaussian Series", paper submitted for publication.

4. Sacksteder, K.R., "A Laser Doppler Anemometer for Measurements in Fuel Sprays," M.S. Thesis, School of Mechanical Engineering, Purdue University, 1982.

TASK II

BIANNUAL REPORT

AFOSR-82-0107

Period November 15, 1981 to November 14, 1983

TASK II

STABILIZATION OF AIRCRAFT FIRES

Principal Investigator:

A.H. Lefebvre

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TECHNICAL OBJECTIVES

One objective of the research was to extend the range of experimental data on the stabilization properties of bluff-body flameholders to include flameholders of large size (characteristic dimension up to 10 cm) and irregular shape, such as might arise on the external surface of an aircraft due to structural damage. Another goal was to derive suitable theoretical relationships for blowoff velocity for the extended range of flameholder sizes and shapes.

APPROACH

The method used to determine the blowoff velocity and other stability characteristics of bluff-body flameholders was the well-established water injection technique, as illustrated schematically in Fig. 1. With this technique the flameholder under test is placed near the exit of a duct supplied with an airflow containing a water/fuel mixture. Both the water and fuel (usually Jet-A) are fully vaporized by the time they reach the flameholder. At the start of a run the equivalence ratio is set and the flame is established with no water injection. The water flow is then initiated and increased until flame extinction occurs. A plot of the stability loop so obtained (equivalence ratio versus water/fuel ratio) represents, in effect, a plot of equivalence ratio versus the reciprocal of pressure. The calculated relationship between water/fuel ratio and the equivalent reduction in gas pressure shows for example, that the injection

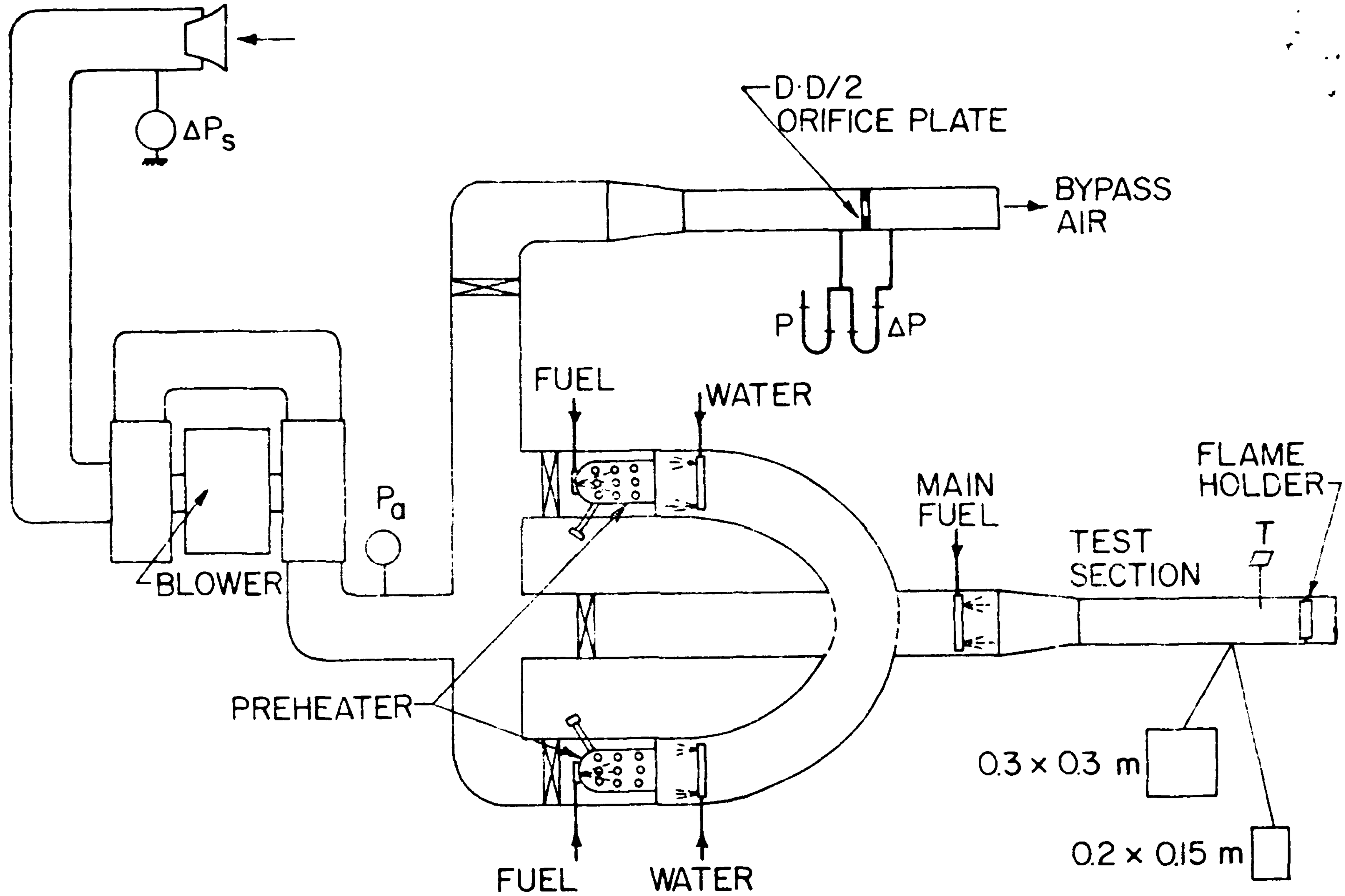


Figure 1. Schematic diagram of apparatus used to measure stability characteristics.

of equal weights of water and fuel is equivalent to halving the pressure. The method has two advantages: it is the only technique which allows the entire stability loop to be obtained for large flameholders, and any subatmospheric pressure can be simulated while using fan air at atmospheric pressure.

Stability loops obtained by the method outlined above can be analyzed to determine the effects of flameholder size, shape, and blockage on blowoff velocity. The separate influences on blowoff velocity of variations in approach stream velocity, ambient gas pressure (altitude) and fuel chemistry, can also be assessed.

PROGRESS

In the first year of the period covered by this report, considerable progress was made, both in the acquisition of extensive experimental data of high quality, and in the application of these data to the development of the following new equation for blowoff velocity.

$$U_{BO}/S_L = C_s(1 - B_a)\ \mathrm{Re}\ \mathrm{Pr} \qquad (1)$$

where
- U_{BO} = blow-off velocity
- S_L = laminar flame speed
- C_s = flameholder shape factor ($=B_a/B_g$)
- B_a = aerodynamic blockage of flameholder
- B_g = geometric blockage of flameholder
- Pr = Prandtl number
- Re = Reynolds number = $(S_L D_c \rho_o/\mu_o)$
- D_c = characteristic dimension of flameholder

An alternative form of Eq. (1), which serves to demonstrate that blowoff velocity is proportional to the square of laminar flame speed, is the following.

$$U_{BO} = C_s \ (1 - B_a) \ (D_c \ S_L^2/\alpha_o) \tag{2}$$

Equations (1) and (2) were found to predict not only the experimental values of blowoff velocity obtained in this AFOSR research program, but also the results obtained by other workers. This very good agreement is demonstrated in Fig. 2.

Thus at the conclusion of the first year period it was considered that one of the primary goals, namely, that of developing an equation for blowoff velocity suitable for large-scale flameholders, had been fully met.

During the early part of the second year of the reporting period, attention was focussed on the influence of fuel type on flame stability. From inspection of Eqs. (1) and (2) it is clear that the only way in which a change in fuel type can affect blowoff velocity is via the laminar flame speed, S_L. However, most hydrocarbon fuel-air mixtures tend to have very similar values of S_L, usually in the range between 0.35 and 0.43 m/s. Thus, at the outset of the investigation it was anticipated that only slight variations would be observed in the stability limits for the proposed test fuels, namely gasoline (JP 4), kerosine (Jet A) and diesel oil (DF2), which had been chosen to represent the range of fuel types likely to be encountered in aircraft jet engines in the forseeable future.

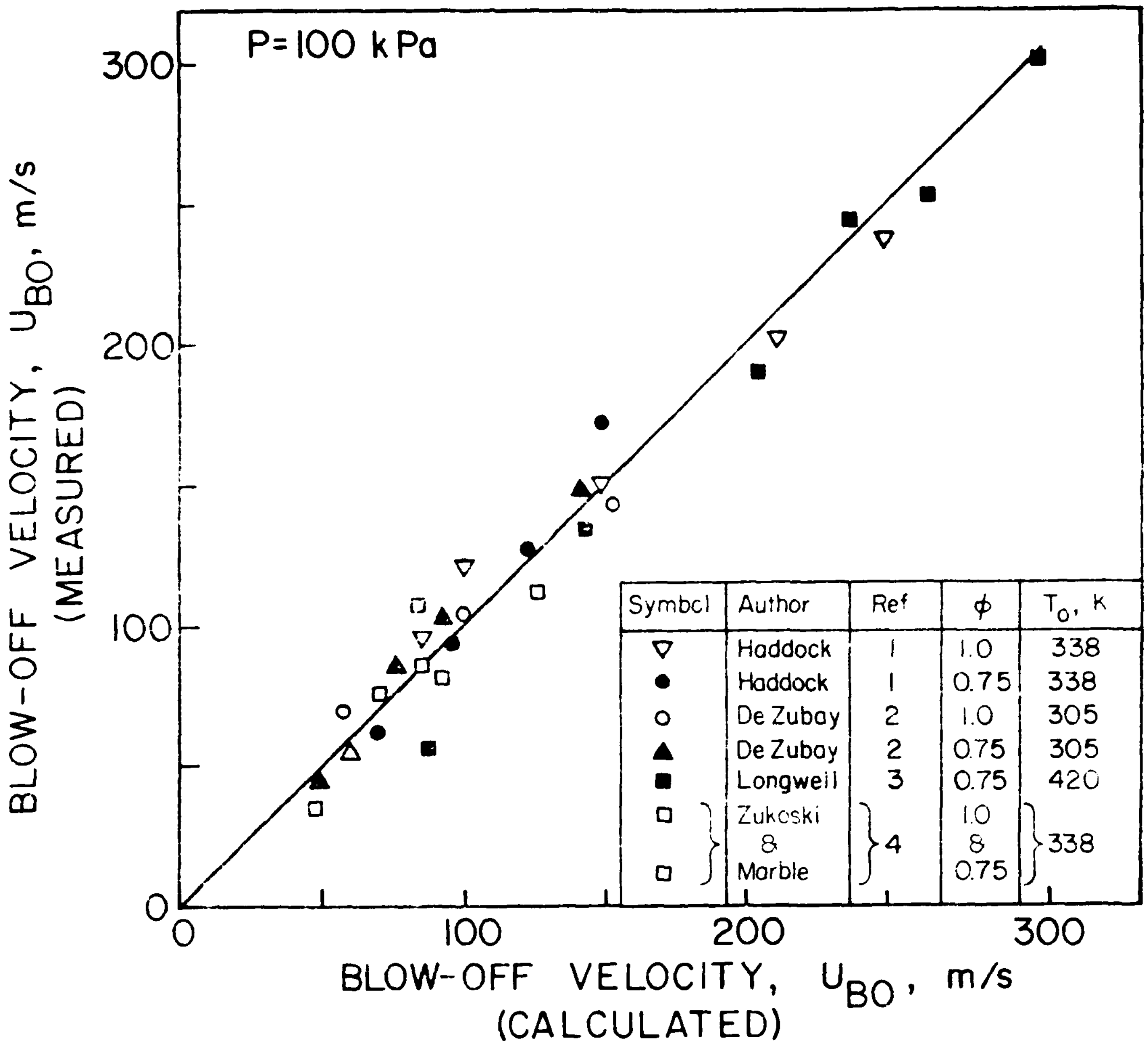


Figure 2. Comparison of measured and predicted values of blowoff velocity.

The results of this research were presented as Paper No. 83-1327 at the AIAA/ASME/SAE 19th Joint Propulsion Conference, held during June 1983, in Seattle, Washington. Some typical results for Jet A, propane, and hydrogen are shown in Fig. 3. It is clear from this figure that the higher flame speed exhibited by hydrogen leads to a considerable expansion of the stability loop.

It was found that the stability loops for gasoline, kerosine and diesel oil are practically the same. The slight observed differences between these fuels is attributed to differences in their latent and sensible heat requirements, which cause the vapor-air mixture for gasoline to be higher than that of kerosine which, in turn, is higher than that of diesel oil. The practical significance of this result is that the threat to aircraft safety from external fires stabilized either by structural protrusions or regions of separated flow on the airframe, is virtually the same for a relatively low volatility fuel, such as diesel oil (DF2) as it is for a fuel of higher volatility, such as JP 4.

During the latter half of the second year of the reporting period, work started on the measurements of stability characteristics, notably blowoff velocity, for flameholders of irregular shape, as illustrated in Fig. 4. Furthermore, detailed measurements of static pressure were carried out both in an around the flameholder region, in order to establish relationships between flameholder pressure drop, flameholder size, shape, aerodynamic drag, and blowoff velocity.

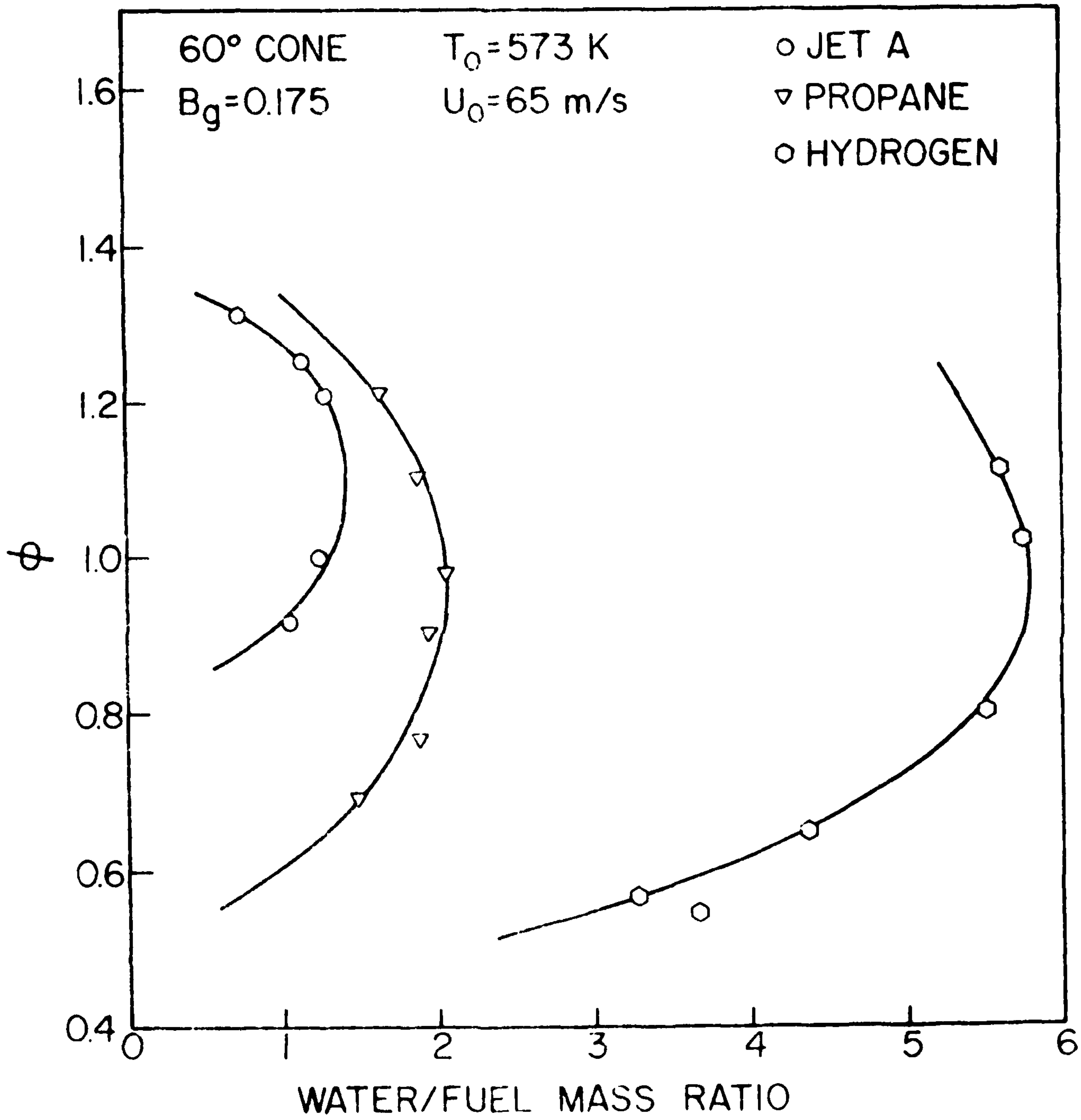


Figure 3. Comparison of stability loops for Jet A, propane and hydrogen.

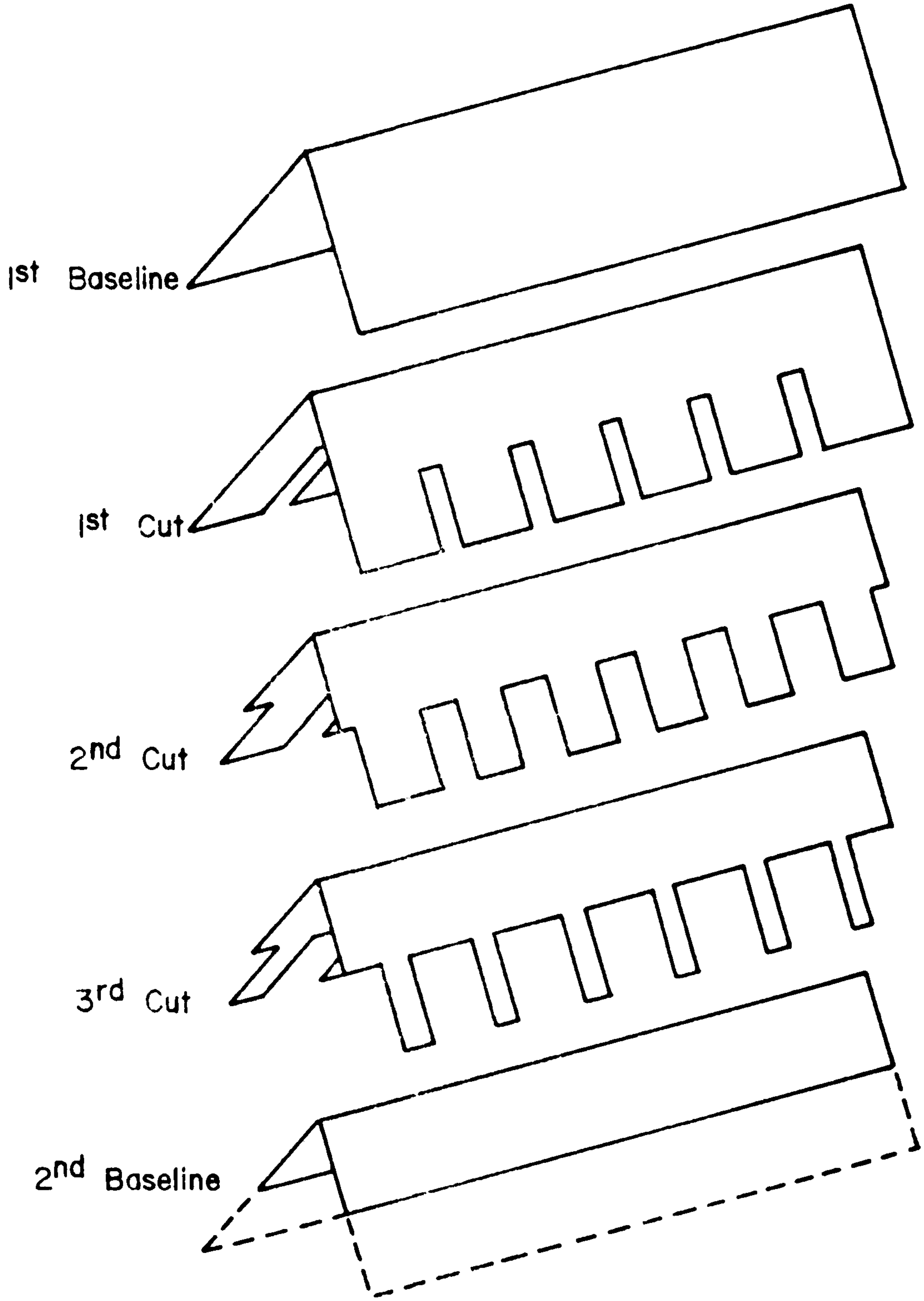


Figure 4. Flameholder geometries employed in irregular-shape test series.

The results of this study were incomplete at the end of the reporting period and it was decided to continue these investigations during 1984.

REFERENCES

1. Haddock, G.W., Flame-Blowoff Studies of Cylindrical Flame Holders in Channeled Flow, Progress Report 3-24, May 1951, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

2. De Zubay, E.A., Characteristics of Disk-Controlled Flame, Aero Digest, Vol. 61, No. 1, pp. 54-56; 102-104, July 1950.

3. Longwell, J.P., Flame Stabilization by Bluff Bodies and Turbulent Flames in Ducts, Fourth Symposium (International) on Combustion, The Williams and Wilkins Company, Baltimore, Maryland, pp. 90-97, 1953.

4. Zukowski, E.E. and Marble, F.E., Flame Stability from Bluff-Body Flameholders, Eighth Symposium (International) on Combustion, pp. 933-943, 1961.

TECHNICAL SIGNIFICANCE

The development of an equation based on sound scientific arguments for the prediction of the blowoff velocity of bluff-body flameholders in terms of all the relevant geometric, aerodynamic, and fuel variables, in considered to be a significant achievement.

Of considerable practical importance is the result obtained by a combination of theory and experiment which showed that the threat to aircraft safety from external fires, stabilized either by structural protrusions or regions of separated flow on the airframe, is virtually the same for all hydrocarbon fuels of present or forseeable interest to the U.S. Air Force.

PUBLICATIONS

The references listed below represent the total number of publications resulting from this program since its inception.

1. Ballal, D.R. and Lefebvre, A.H., "Weak Extinction Limits of Turbulent Flowing Mixtures," Trans. ASME, J. Eng. Power, Vol. 101, No. 3, pp. 343-348, 1979.

2. Ballal, D.R. and Lefebvre, A.H., "Weak Extinction Limits of Turbulent Heterogeneous Fuel/Air Mixtures," Trans. ASME. J. Eng. Power, Vol. 102, No. 2, pp. 416-421, 1980.

3. Ballal, D.R. and Lefebvre, A.H., "Some Fundamental Aspects of Flame Stabilization," Fifth International Symposium on Airbreathing Engines, pp. 48/1-8, 1981.

4. Rao, K.V.L. and Lefebvre, A.H., "Flame Blowoff Studies Using Large-Scale Flameholders," Trans. ASME J. Eng. Power, Vol. 104, No. 4, pp. 853-857, 1982.

5. Rizk, N.K. and Lefebvre, A.H., "Influence of Laminar Flame Speed on the Blowoff Velocity of Bluff-Body Stabilized

Flames," paper presented at the AIAA/ASME/SAE 19th Joint Propulsion Conference, Seattle, Washington, June 27-29, 1983. This paper has since been accepted for publication in the AIAA Journal.

PERSONNEL

During the two-year reporting period the key personnel employed on this program, in addition to the principal investigator (A.H. Lefebvre) were visiting scholars Dr. K.V.L. Rao and Dr. N.K. Rizk, and graduate student R.M. Stwalley.

AWARDS

The paper "Flame Blowoff Studies Using Large-Scale Flameholders" received both the 1982 ASME Combustion and Fuels Award and the 1984 ASME Gas Turbine Award.

TASK III

TASK III - SUMMARY

1. Reporting Period: 11-15-81 to 11-14-83

2. Starting Date: 11-15-81

3. Objective: The objective is the determination of flame structure, propagation and quenching characteristics in a so-called void space with (a) small air flow, (b) low pressure fuel injection through a protrusion, (c) small ventilation, and (d) gravitational action normal to both air flow and fuel injection.

4. Application: The research project is relevant to (a) aircraft void space fires and thus aircraft fire safety, (b) gas turbine combustor design with fuel injectors protruding into the chamber, and (c) ramjet combustor configurations with "blockage". Fundamental data pertaining to (a) a jet through a protrusion in cross-flow and (b) flame stability when the jet consists of fuel and there is an ignition source will be the principal contribution.

5. Status: Analytical-computational studies have been continued on jet flow through a protrusion in cross-flow when the jet and cross-flow velocities are small and of the same order. Experimental studies have been completed on (a) ventilation flow into a cavity with small internal flow and (b) visualization of flow in the presence of a protrusion, including the case of jet through the protrusion. The test rig for combustion studies with gaseous fuel injection has been set up.

6. Publication: A paper is under preparation for the AIAA Propulsion Conference, Juen 1984

7. Interactions: In view of the direct-implications to the group dealing with fires at the Wright-Patterson AFB, a seminar-type presentation has been given there on a six-monthly basis. Discussions have also been held with personnel at the NBS, the Boeing Military Airplane Co. and the Sandia National Laboratories, Livermore, Ca. Secondly, in view of the implications of the research to the development of gas turbine and ramjet combustors, discussions have been held with personnel of the General Electric Co. and the Naval Weapons Center.

1. Introduction

During 1984-85, two major topics of research have received attention.

(i) Ventilation flow into a cavity with small flow on it; and

(ii) Jet through a protuberance in a cross flow.

In both cases, experimental studies have been undertaken with a specifically-[illegible] test rig. In case (ii) modelling and computational prediction have [illegible] initiated and [illegible] obtained.

[illegible]

[illegible] a protuberance in a cross flow.

1.1. Relevance

In the general problem of [illegible] cavity [illegible] surroundings through [illegible] opening, on account of [illegible] difference, no data have been available on the influence of the velocity ratio between the surroundings and the cavity. [illegible] are of interest in [illegible] and in aircraft [illegible] to low speed and [illegible] flows in cavities [illegible].

[illegible] flow [illegible] have been reported [illegible] no data [illegible] through a [illegible] relevance [illegible] tions between the [illegible] flow and the jet [illegible] geometry [illegible] and mixing [illegible] are of great [illegible] represents the [illegible] of the fuel tank [illegible] fuel injection block [illegible] in fuel lines [illegible] illustrated in Figure 1.)

[illegible]

[illegible] test cavity

[illegible] cavity

(2) with the free stream flow is also shown in the figure. The speed and pressure of airflow can be adjusted in (1) and (2); the velocity can be varied in the range of 10-25 mps in (1) and 20-100 mps in (2), and the pressure difference between (1) and (2), 0.5-1.2 psi. Cavity (1) is the actual test section and (2) represents the "surrounding" or "adjoining external" flow. Figure 2.1 also indicates the gravitational action direction, noting that gravity is a consideration in low speed combusting flows.

The test rig has been utilized for (a) flow visualization and (b) measurement of overall flow quantities.

In cavity (1), the test section, a variety of protrusions can be incorporated as well as various shapes of walls for attaching the protrusions. These are illustrated in Fig. 2.2.

By mixing smoke into the low speed jet flow, one can study the jet mixing and spreading characteristics.

2.2. Test Rig for Combustion Studies

The test rig is essentially the same as illustrated in Fig. 2.1. Modifications have been made by (a) replacing (1) and (2) with stainless steel and steel bodies, respectively, (b) providing methane gas injection into the test section (1), (c) introducing an ignitor, and (d) locating quartz windows for optical observation.

Other instrumentation and diagnostics are being examined.

The ignitor design is shown in Fig. 2.3. It can be observed that the source of ignition can be moved both radially and circumferentially in relation to the jet through the protrusion and the gravitational direction.

3. Ventilation Flow

Figure 3.1 provides (a) the parameters that were varied during the tests for establishing ventilating flow into region (1) from the external stream (2); and (b) the broad conclusions from the study.

Figure 3.2 shows a correlation of flow into (1) utilizing the pressure difference and flow velocity difference as parameters. The mass flux $\dot{m}$ of air flowing into cavity (1), through a vent of area of cross-section A, when the density, dynamic head and pressure difference are ρ_1, q_1 and Δp_{12}, is shown as a function of the parameter I.

4. Diagnostics of Flow Past a Protrusion with a Jet

Utilizing several visualization and photographic techniques, the nature of the flow generated in the vicinity of protrusions has been determined.

Typical details of flow are shown in Figs. 4.1 and 4.2.

The flow field in the jet is basically time-dependent in relation to the internal structure. The frequency of such structures has been obtained utilizing a stroboscopic light source. Some typical data have been provided in Fig. 4.3.

The type of data presented in Figs. 4.1-4.3 illustrate the manner in which mixing and jet spread can arise (a) upstream, (b) over and (c) downstream of the three-dimensional protrusion.

5. Modelling and Prediction

The flow past a protrusion with a jet issuing through it is being modelled in several steps as follows. In all cases, incompressible, viscous flows have been considered.

(i) Flow past a protrusion when the cavity flow and protrusion are two-dimensional.

(ii) The foregoing case with a two-dimensional (slit-type) jet issuing through the protrusion.

(iii) Flow past a cylindrical protrusion with a jet issuing out of it, this case being fully three-dimensional.

5.1. Computational Scheme

A source program, commonly referred to as the PHOENIX, developed by CHAM, Ltd. under the guidance of D.B. Spalding, has been acquired under the Project and utilized with appropriate modifications.

The main cavity flow is air considered as a perfect gas, low speed, laminar flow. The jet may consist of any gas; air, carbon-dioxide and methane have been considered. The ratio of main flow velocity to jet velocity is either one or three.

The problem has been formulated as a parabolic one with given initial flow conditions for the cavity and the jet flows.

Although the CYBER 205 is fully operational now at Purdue Univesrity, all of the results presented here have been obtained utilizing the front machine, namely the CDC 6600. The total number of nodes utilized is between 5,000 and 8,000 in various cases.

5.3. Results

Figures 5.1 and 5.2 present the cavity and protrusion geometry and the computational domain in the two-dimensional and in the three-dimensional cases, respectively. The initial conditions for the main cavity flow are uniform streamwise velocity and uniform pressure. Similarly, the initial conditions for the jet flow are uniform normal velocity and uniform pressure. It is assumed that the jet exit pressure is the same as the cavity main flow entry pressure, although the main cavity flow may suffer a slight pressure loss between entry and the location of the protrusion.

Table 5.1 presents the initial conditions for the various calculations.

Figures 5.3-5.11 present the computer outputs for various cases as described in Table 5.2.

6. Current Activity and Plans

(a) The test rig for combustion studies is being completed.

(b) The test rig for cold flow studies is being utilized for the balance of flow visualization studies, which are expected to be completed by March, 1984.

(c) The ignitor assembly is being manufactured. Methane combustion studies are expected to be undertaken March to September, 1984, principally for obtaining data on relation of ignitor location and injection and flow parameters to flame stability.

(d) The three-dimensional flow prediction scheme will be further developed during 1983-84.

(e) Instrumentation for detailed analysis of combustion processes will be developed during 1983-84.

LIST OF TABLES

	Velocity (m/sec)	Pressure (atm)	Protrusion Height R_e ($R_e \equiv Wh/\nu$)
freestream	Uniform: 30.0	1.0	252.8
jet	Uniform: 30.0	1.0	252.8

Table 5.1. Initial Conditions for Jet and Upstream Flows. (Note: The pressure loss in the free-stream has been neglected when jet is turned on.)

LIST OF FIGURES

AIR FILLED PIPE

WATER FILLED PIPE

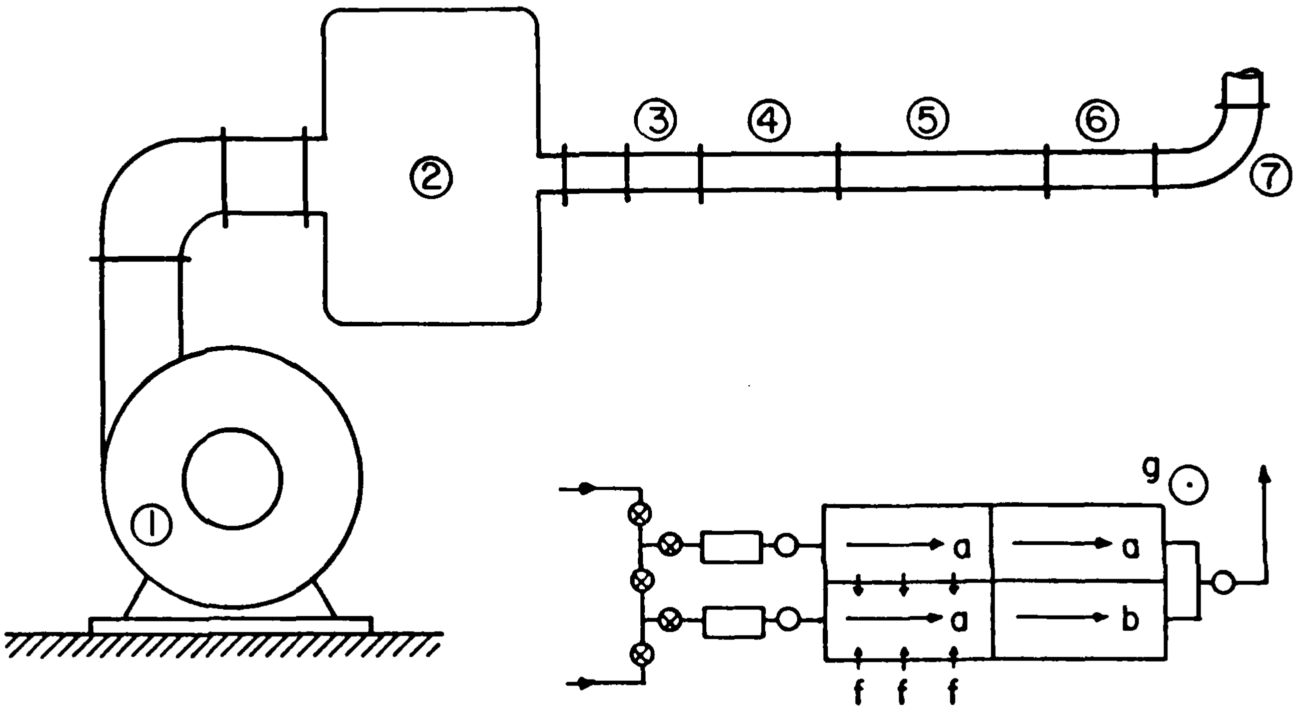
AVTAG FILLED PIPE

DAMAGE TO PIPES (38mm DIA) BY AN INCENDIARY ROUND

REAR PLATE BEHIND AIR FILLED PIPE

REAR PLATE BEHIND WATER FILLED PIPE

FIG. 1.1 TEST ARTICLES: DAMAGED FUEL LINES



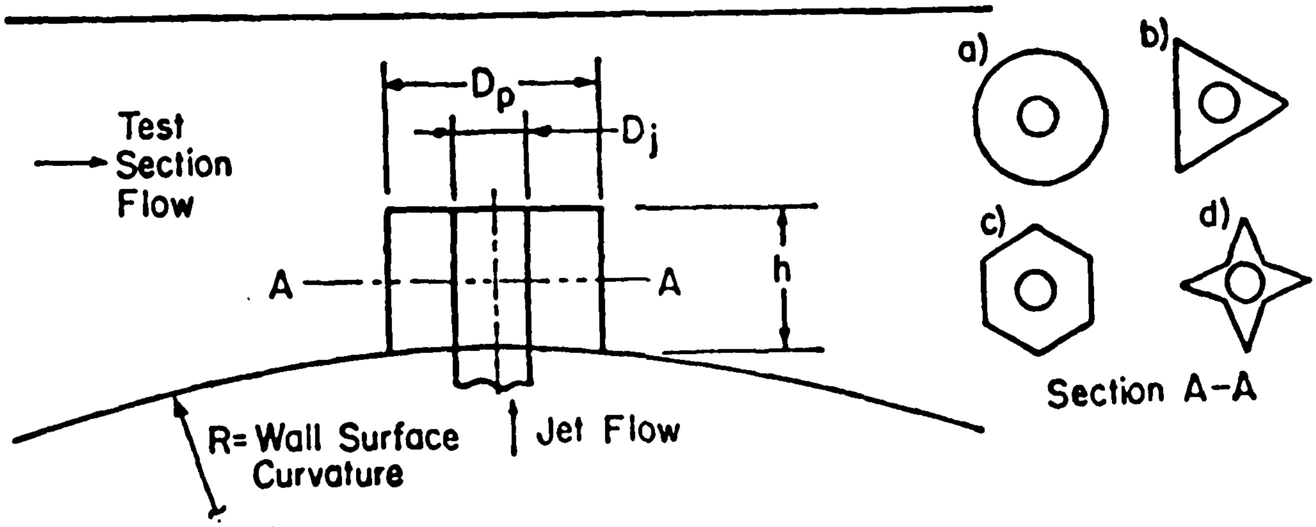
1. BLOWER
2. SETTLING CHAMBER
3. FLOW DIVIDER SECTION
4. FLOW STRAIGHTENER SECTION
5. TEST SECTION: VOID SPACE SIMULATOR
6. FLOW DISCHARGE SECTION
7. EXHAUST

- TEST SECTION: 15×10×60 cms
- FREE AIR FLOW VELOCITY: 20 – 100 m/s

FIG. 2.1 VOID SPACE SIMULATOR TUNNEL

JET THROUGH A PROTRUBERANCE IN A CROSS FLOW

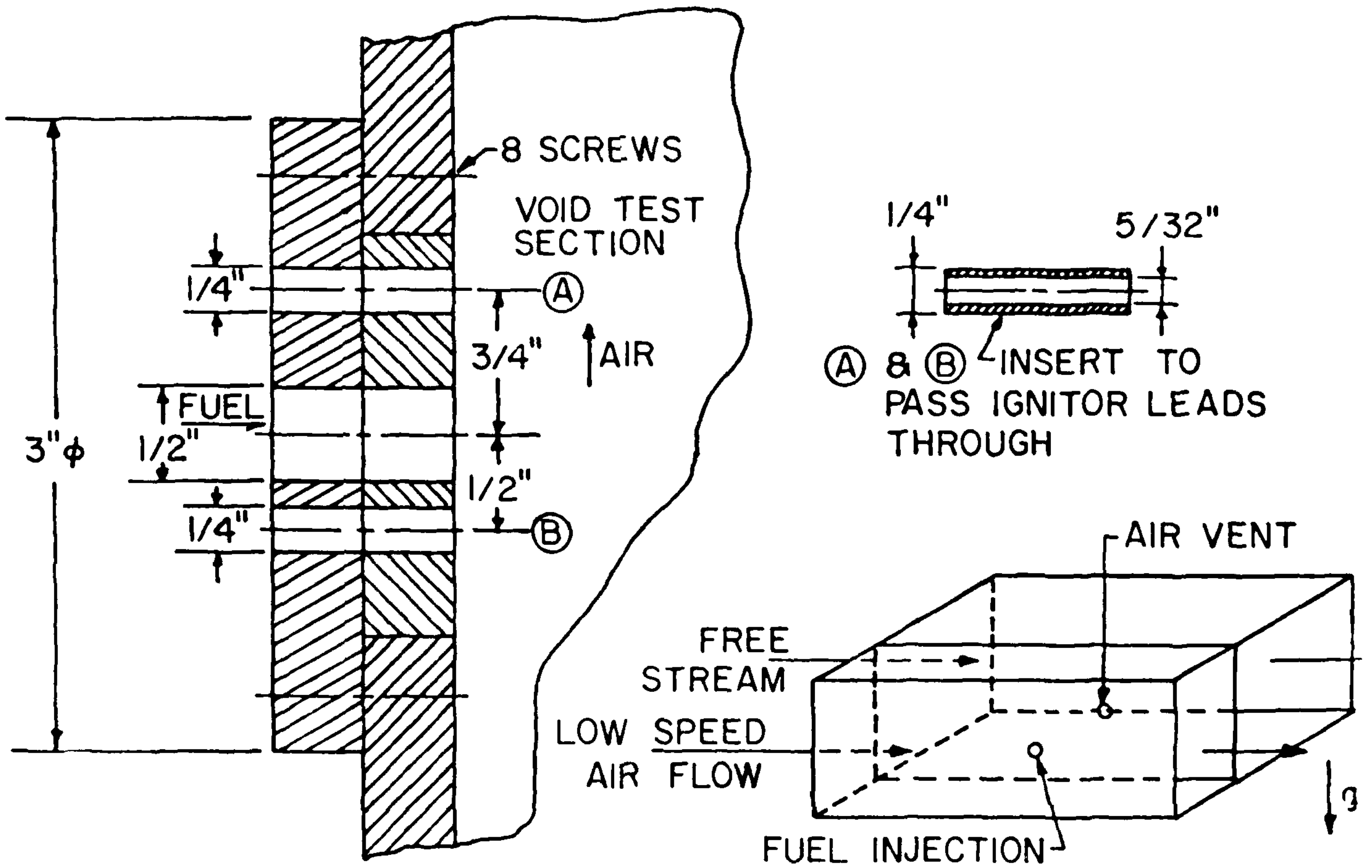
- PARAMETERS



Jet in a Crossflow Through a Protruberance

PARAMETER	RANGE
D_p	0.5 in.
h	0.125-0.5 in.
D_j/D_p	0.125-0.75 in.
R	∞, + and -
V_1	10-50 fps
$Re_{L=1\,ft}$	$50-250 \times 10^3$

FIG. 2.2 JET THROUGH A PROTRUBERANCE IN A CROSS FLOW



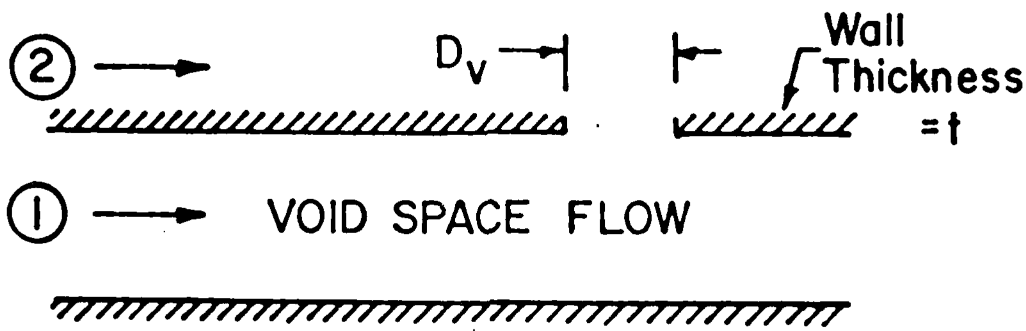
PARAMETER:

- LOCATION OF IGNITION SOURCE
  - RADIUS
  - ANGLE RELATIVE TO 'g' DIRECTION
  - PROTRUSION RELATIVE TO WALL

FIG. 2.3 IGNITOR LOCATOR

FLOW THROUGH AIR VENT

- PARAMETERS



- REGIMES WITH $\Delta P_{012} > 0$

  $\Delta P_{012} = P_{01} - P_2$; $\Delta P_{12} = P_1 - P_2$

  1. $V_1 > V(\Delta P_{12}/2\rho)$ and $> V_2$
  2. $V_1 <$ " and $> V_2$
  3. $V_1 <$ " and $< V_2$

- CONCLUSIONS
  1. VORTEX FORMATION IN CASE 2
  2. FLOW BIDIRECTIONAL IN CASE 2
  3. FLOW NONSTEADY IN CASES 2 & 3
  4. FLOW REDUCED IN CASE 3 COMPARED TO CASE 1

  — BASED ON CONSTANT D & D/t

FIG. 3.1 FLOW THROUGH AIR VENT: PARAMETERS

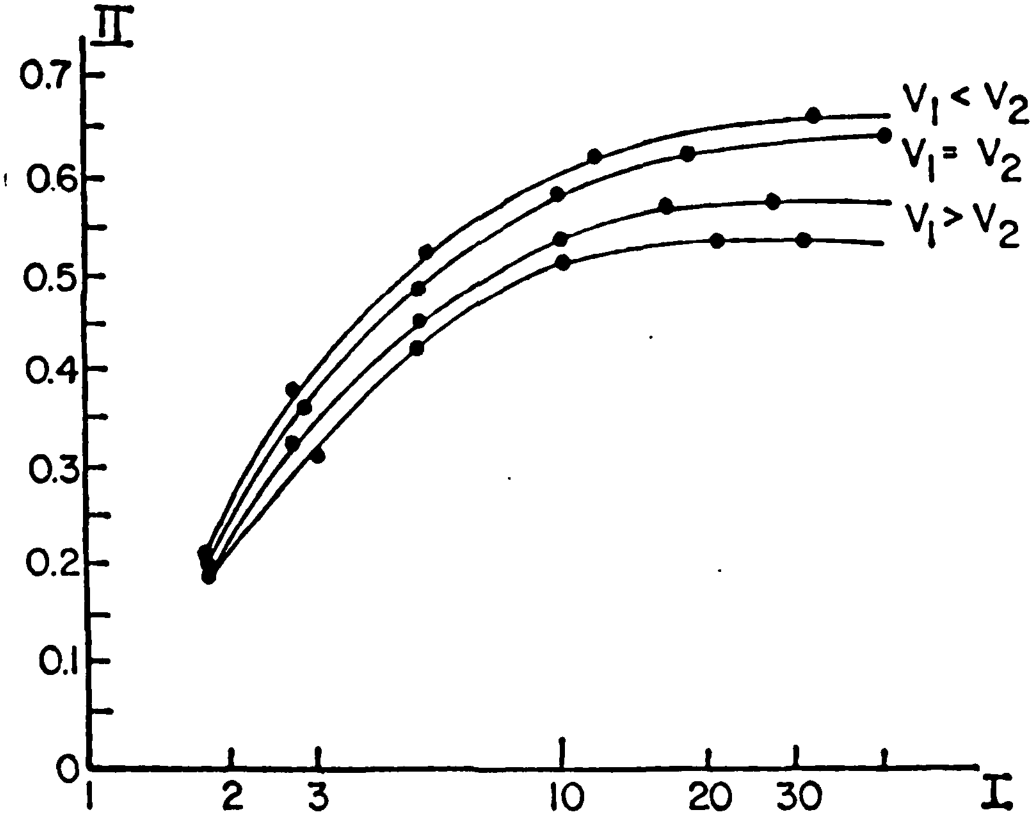
FLOW THROUGH AIR VENT (CONTINUED)

- RANGES OF PARAMETERS

  $D \sim 0.25 - 0.50$ in.

  $\Delta P_{12} \sim 0.5 - 1.50$ psi

  $V_1, V_2 \sim 30 - 75$ fpm



$$\mathrm{I} \equiv \left[1 + \Delta P_{12} / q_1\right] \; ; \quad \mathrm{II} \equiv \dot{m} / \left[A \cdot \rho_1 \cdot \mathrm{I}^{1/2}\right]$$

FIG. 3.2 CORRELATIONS OF FLOW THROUGH VENT

FLOW VISUALIZATION

- FOG JUICE SMOKE
- WOOL TUFTS
- CARBON-CRISCO PAINT

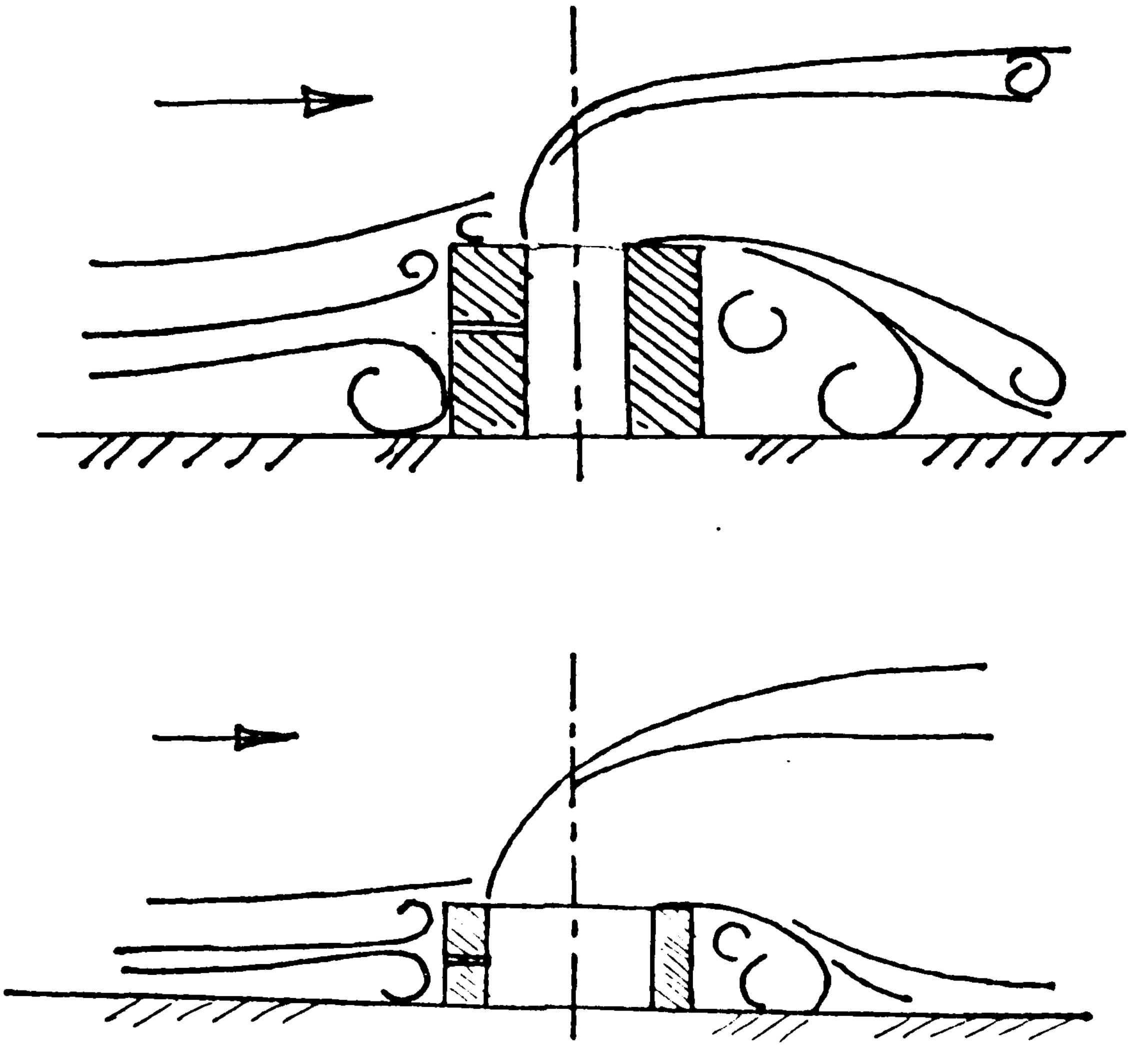


FIG. 4.1 FLOW VISUALIZATION

•EXTRACTED FROM FLOW VISUALIZATION

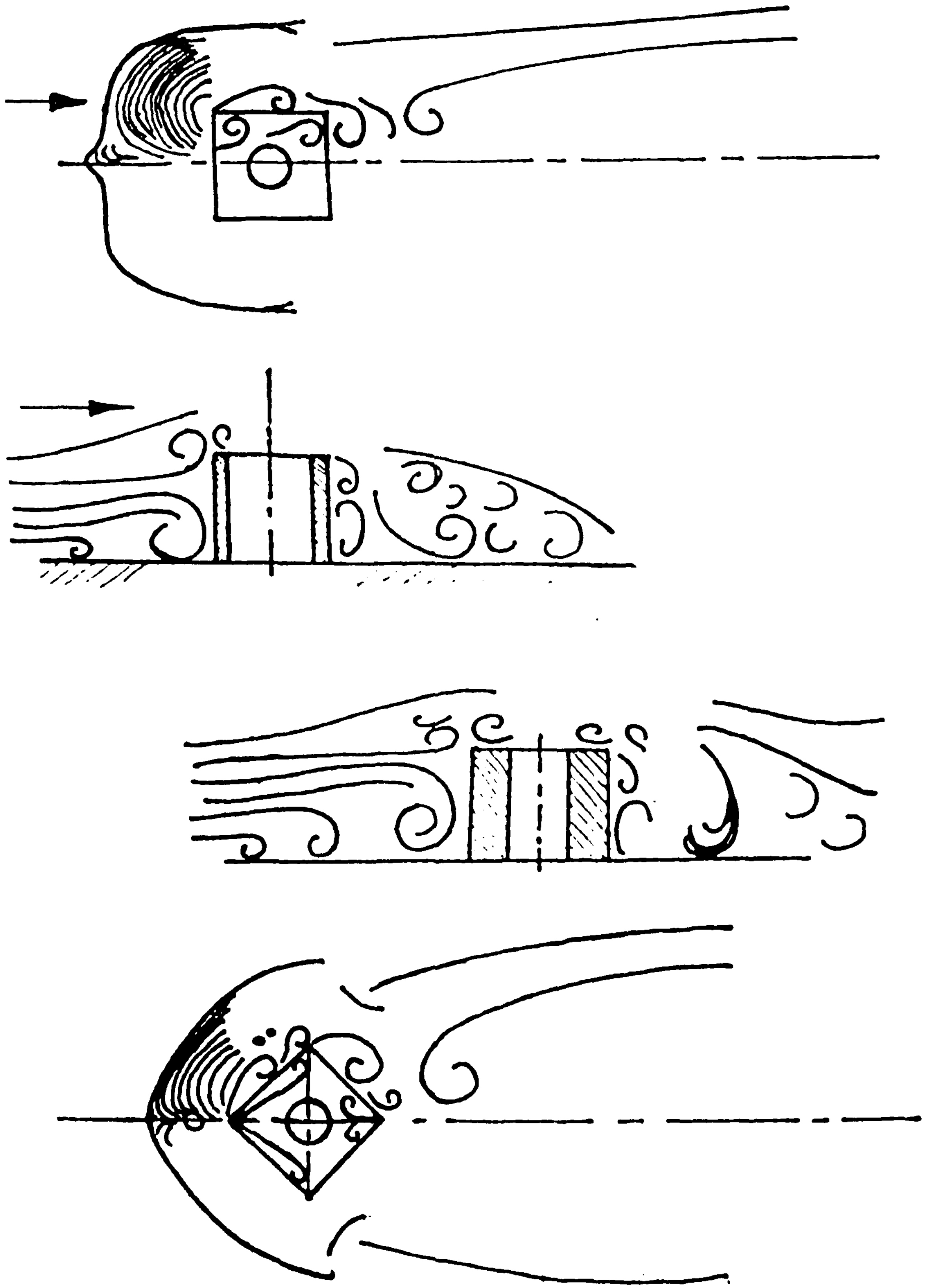
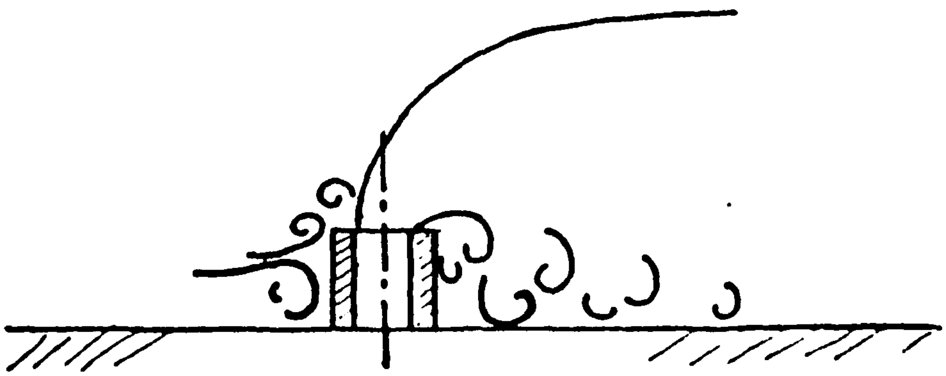


FIG. 4.2 FLOW PATTERNS EXTRACTED FROM FLOW VISUALIZATION

JET INTERACTIONS

	D_j/D_p	h	ω
• CIRCULAR CYLINDER	0.250	0.125	30
		0.500	20
	0.750	0.125	40
		0.500	20
• CUBOID	0.250	0.125	25
		0.500	20
	0.750	0.125	45



- CLOSED STREAMSURFACES DO NOT FORM
- TOTAL NUMBER OF SEP. & ATTACH.
  $\simeq$ TOTAL NUMBER OF NODES AND SADDLES

FIG. 4.3 JET INTERACTIONS

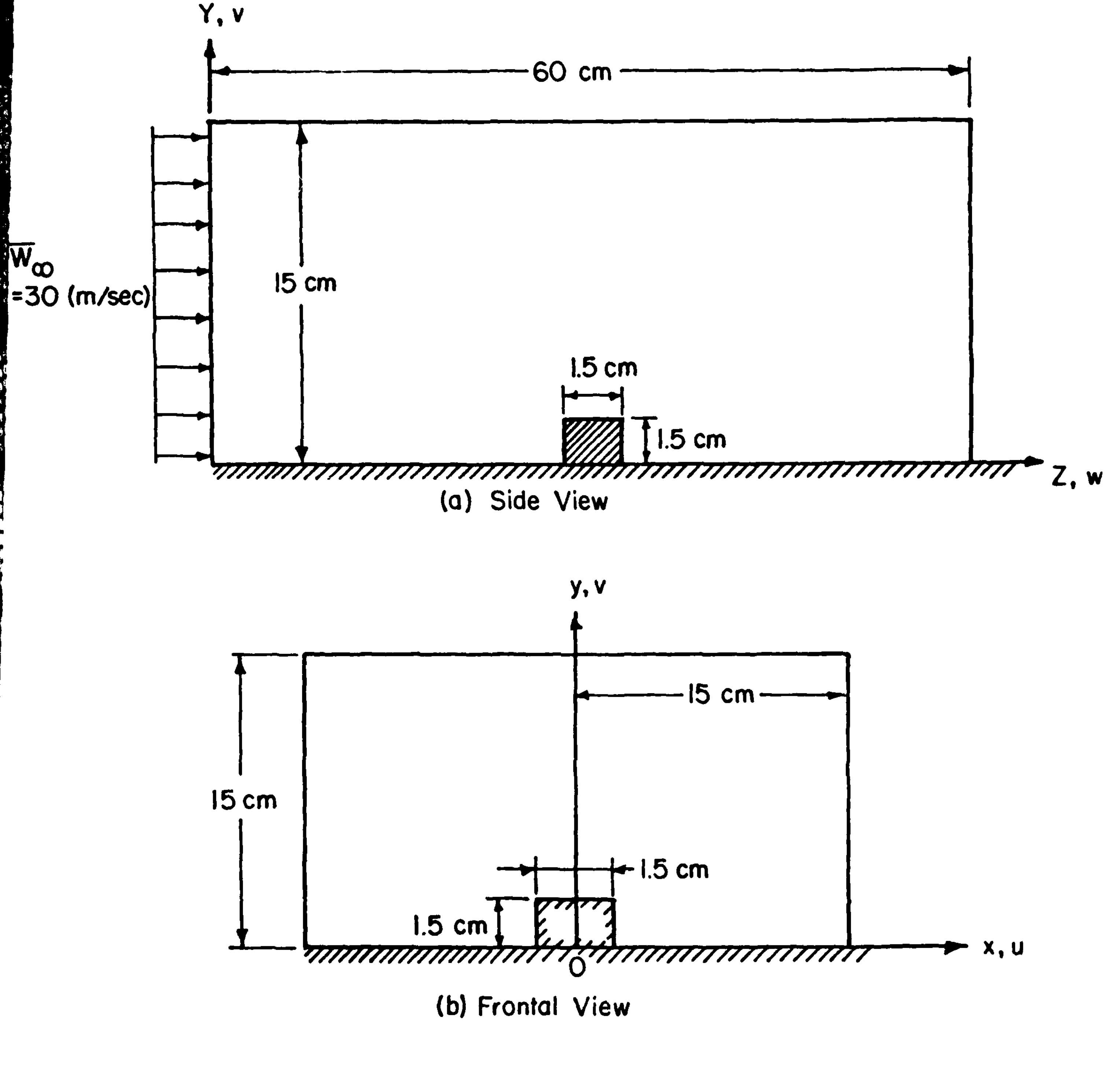


Figure 5.1. Side View (a) and Frontal View (b) of Cavity Geometry

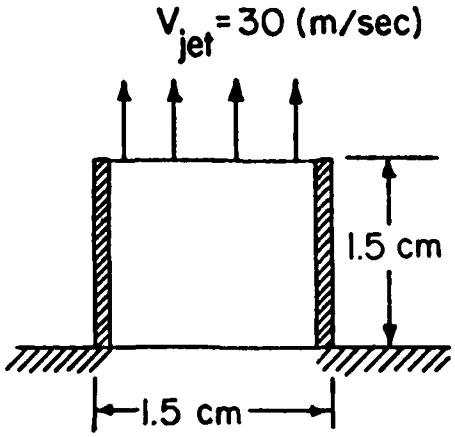


Figure 5.2. Geometry of Protrusion with Jet

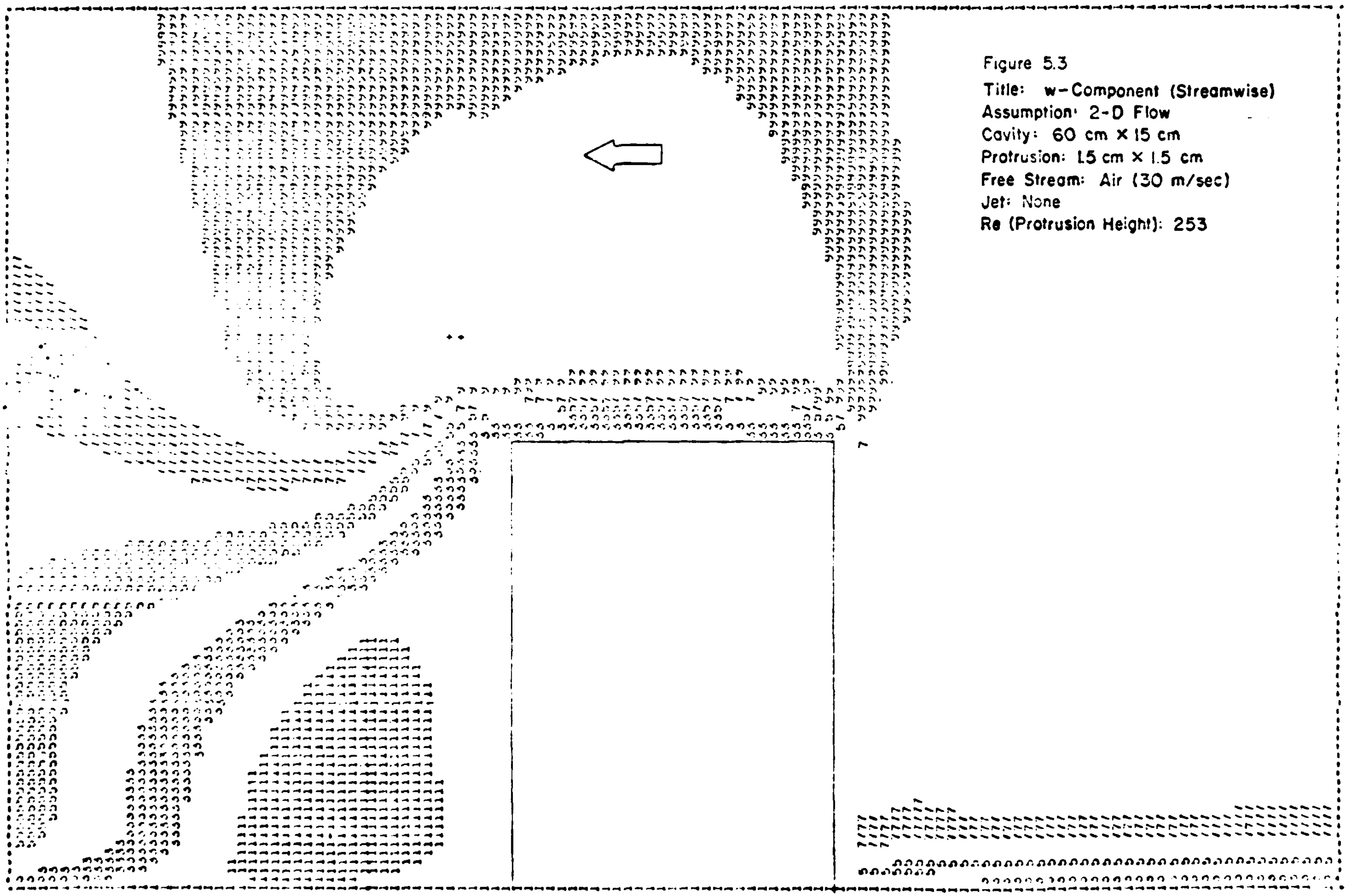


Figure 5.3
Title: w-Component (Streamwise)
Assumption: 2-D Flow
Cavity: 60 cm x 15 cm
Protrusion: 1.5 cm x 1.5 cm
Free Stream: Air (30 m/sec)
Jet: None
Re (Protrusion Height): 253

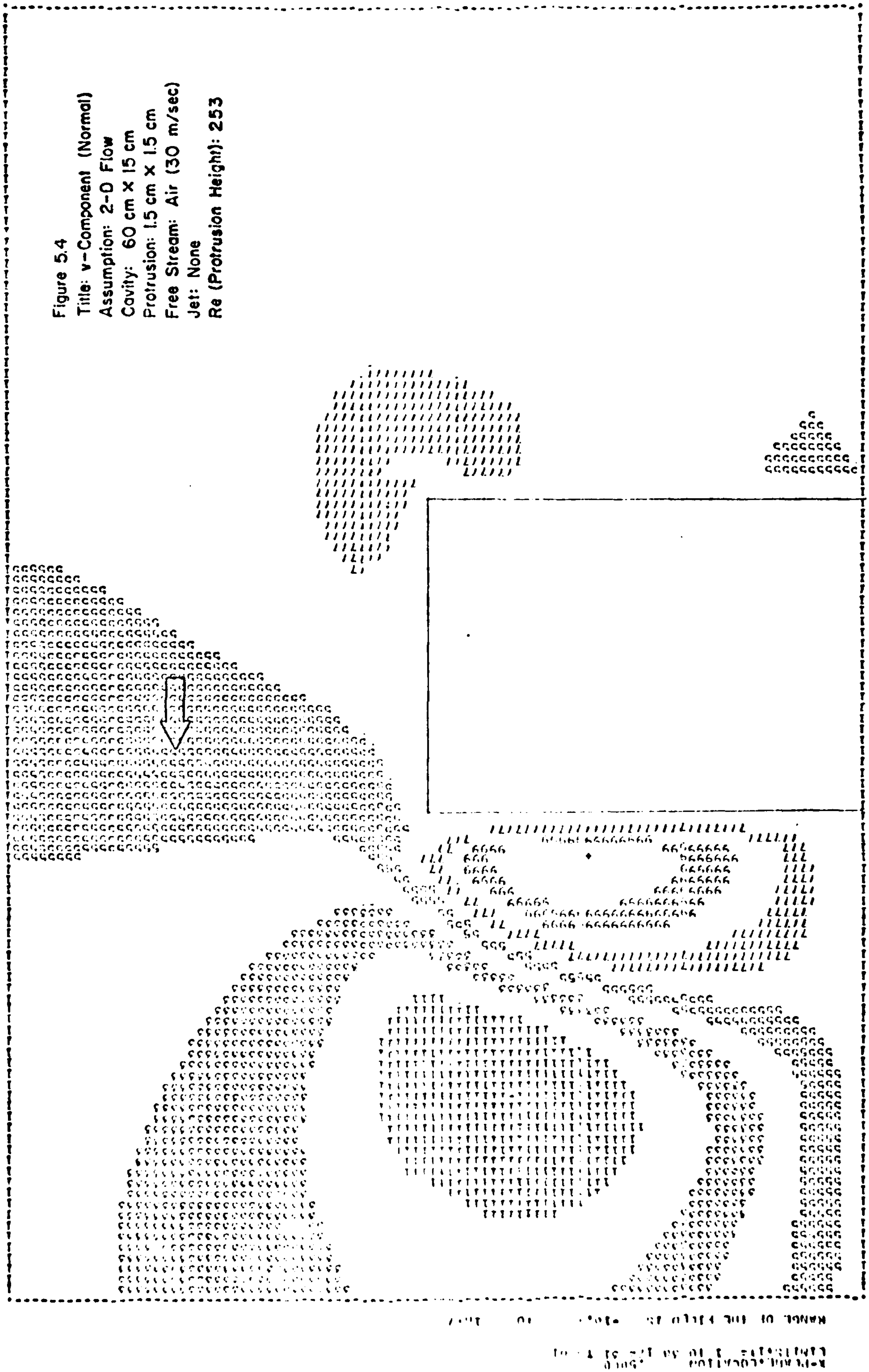


Figure 5.4
Title: v-Component (Normal)
Assumption: 2-D Flow
Cavity: 60 cm x 15 cm
Protrusion: 1.5 cm x 1.5 cm
Free Stream: Air (30 m/sec)
Jet: None
Re (Protrusion Height): 253

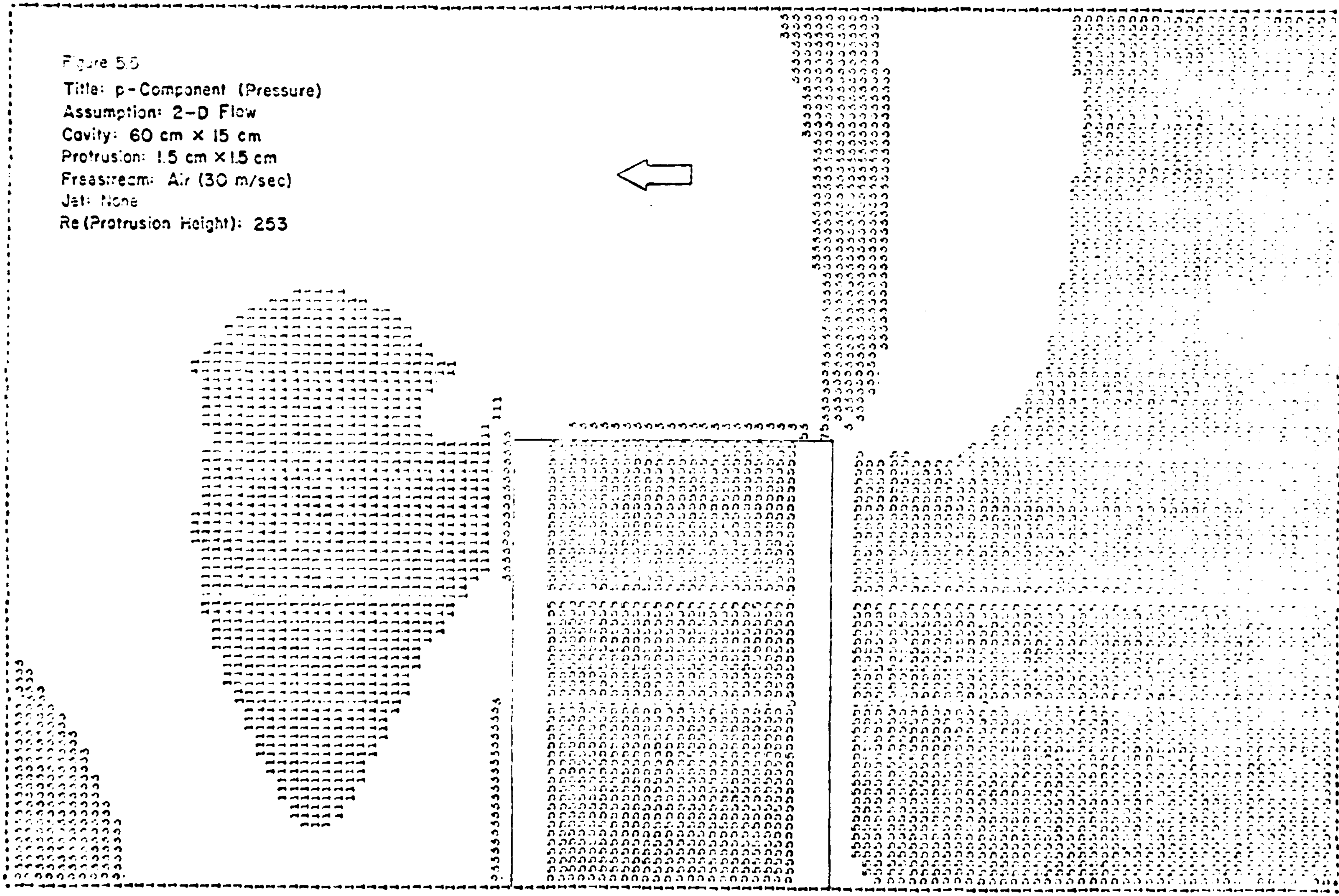


Figure 5.5

Title: p-Component (Pressure)
Assumption: 2-D Flow
Cavity: 60 cm × 15 cm
Protrusion: 1.5 cm × 1.5 cm
Freestream: Air (30 m/sec)
Jet: None
Re (Protrusion Height): 253

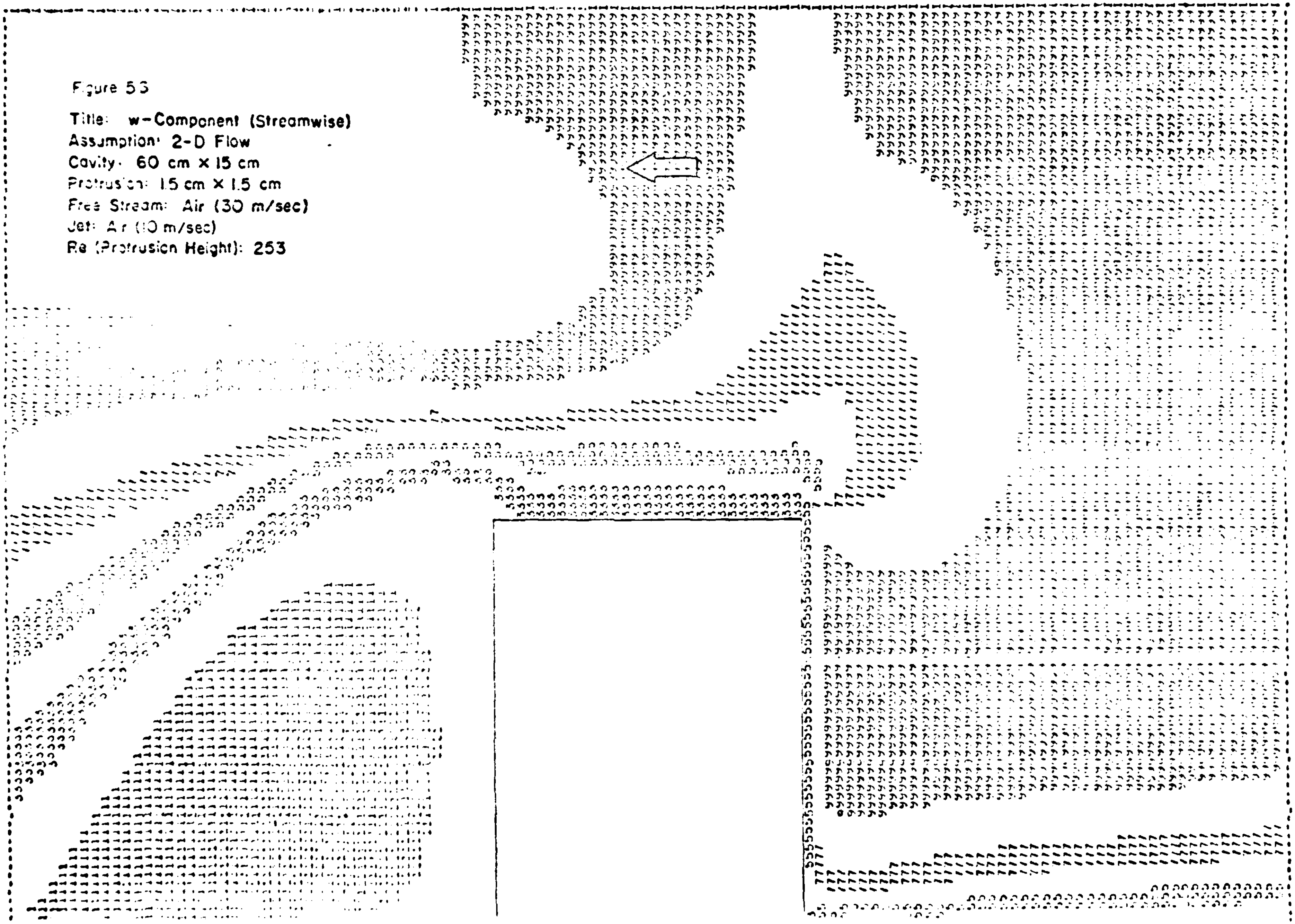


Figure 53

Title: w-Component (Streamwise)
Assumption: 2-D Flow
Cavity: 60 cm × 15 cm
Protrusion: 1.5 cm × 1.5 cm
Free Stream: Air (30 m/sec)
Jet: Air (10 m/sec)
Re (Protrusion Height): 253

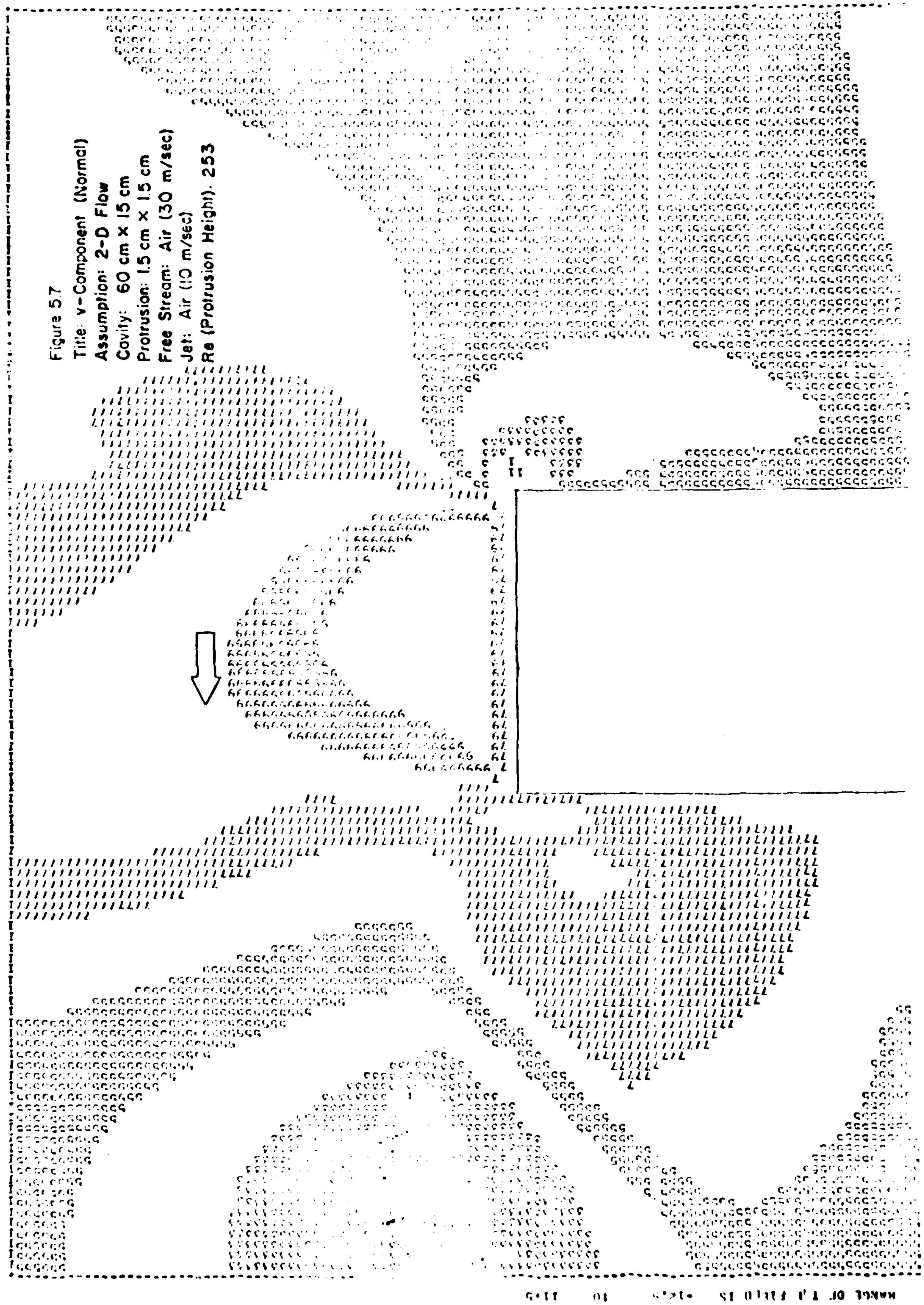


Figure 5.7
Title: v-Component (Normal)
Assumption: 2-D Flow
Cavity: 60 cm × 15 cm
Protrusion: 1.5 cm × 1.5 cm
Free Stream: Air (30 m/sec)
Jet: Air (10 m/sec)
Re (Protrusion Height): 253

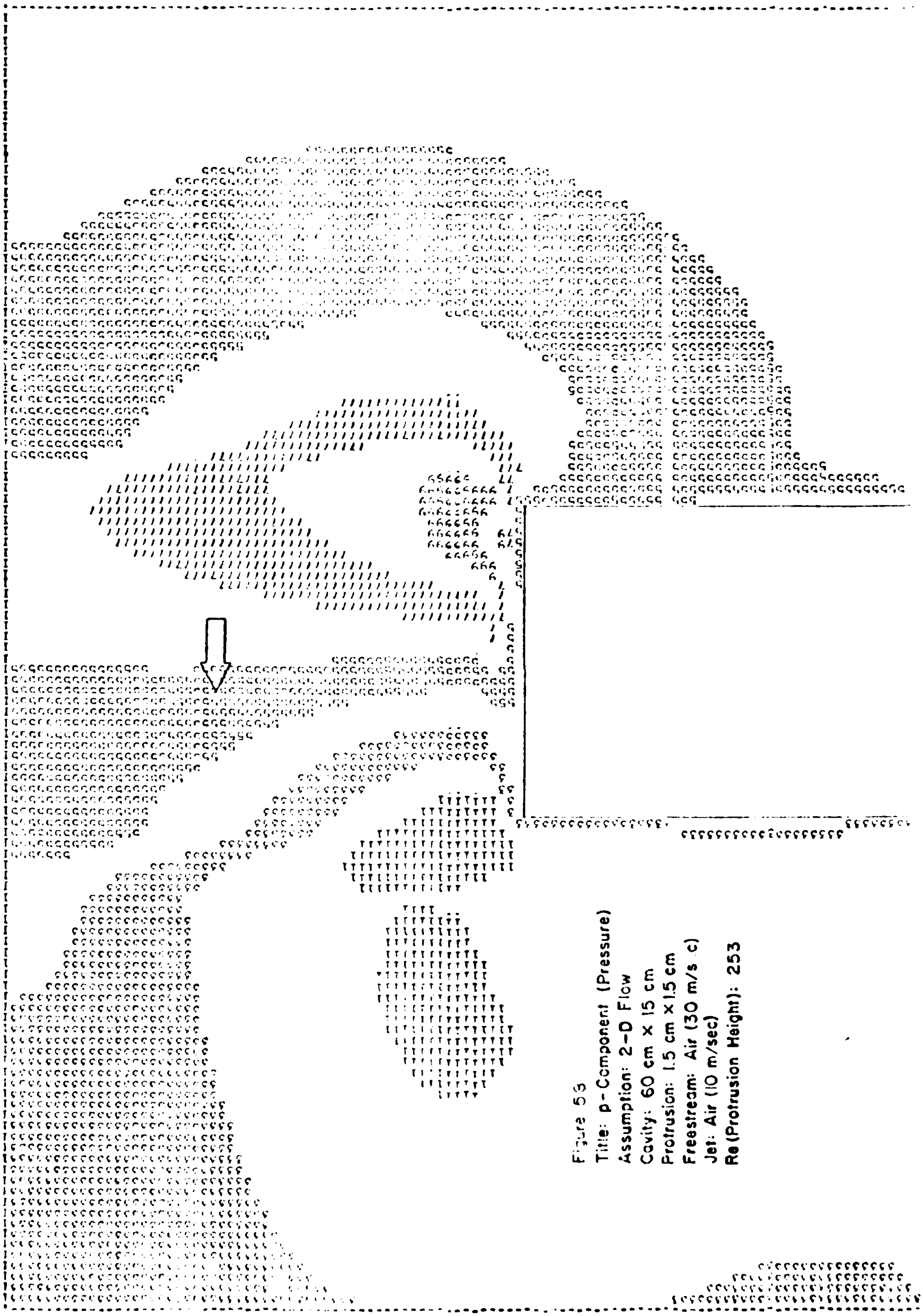


Figure 53
Title: p-Component (Pressure)
Assumption: 2-D Flow
Cavity: 60 cm X 15 cm
Protrusion: 1.5 cm x 1.5 cm
Freestream: Air (30 m/s c)
Jet: Air (10 m/sec)
Re (Protrusion Height): 253

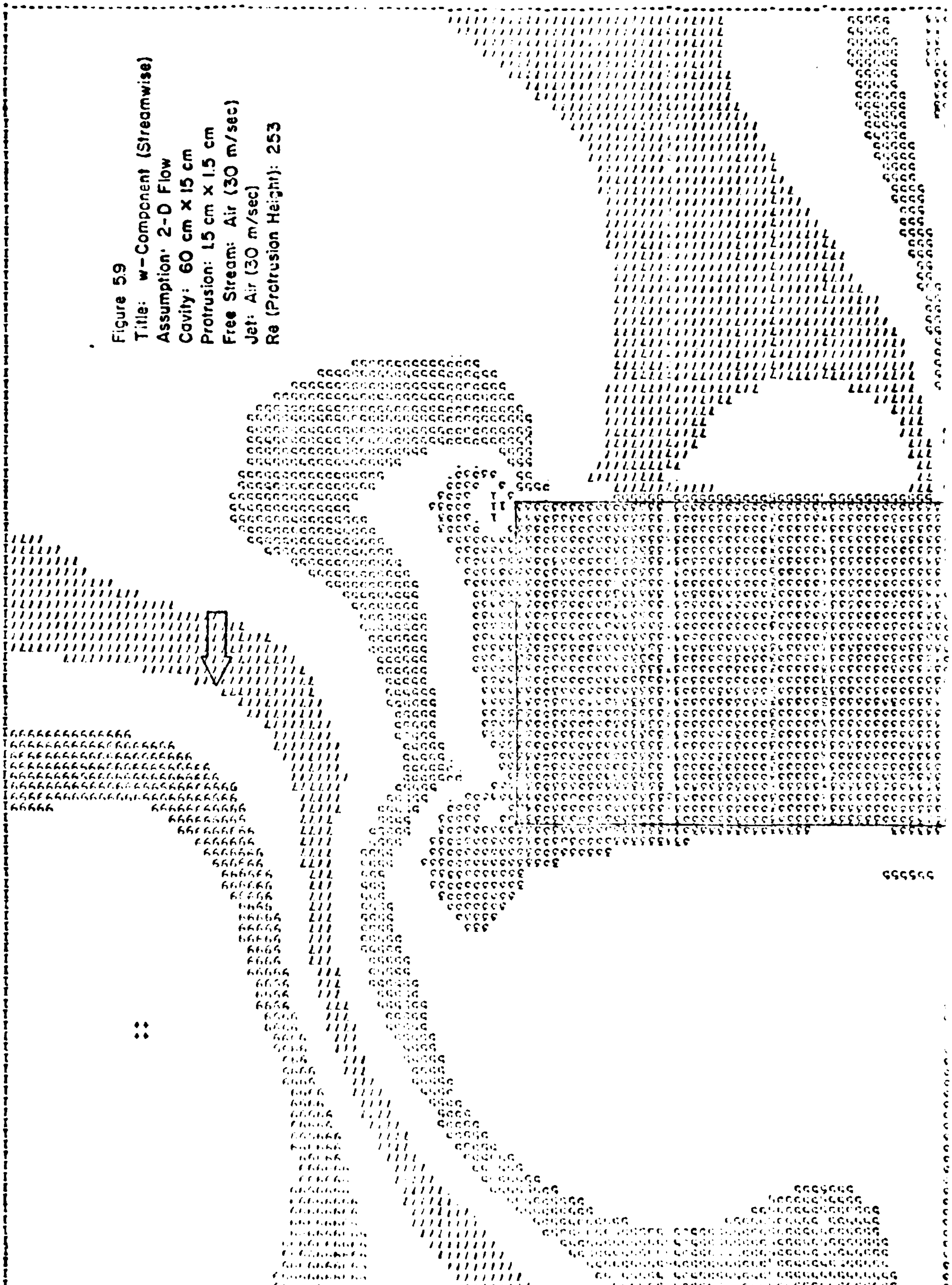


Figure 5.9
Title: w-Component (Streamwise)
Assumption: 2-D Flow
Cavity: 60 cm x 15 cm
Protrusion: 1.5 cm x 1.5 cm
Free Stream: Air (30 m/sec)
Jet: Air (30 m/sec)
Re (Protrusion Height): 253

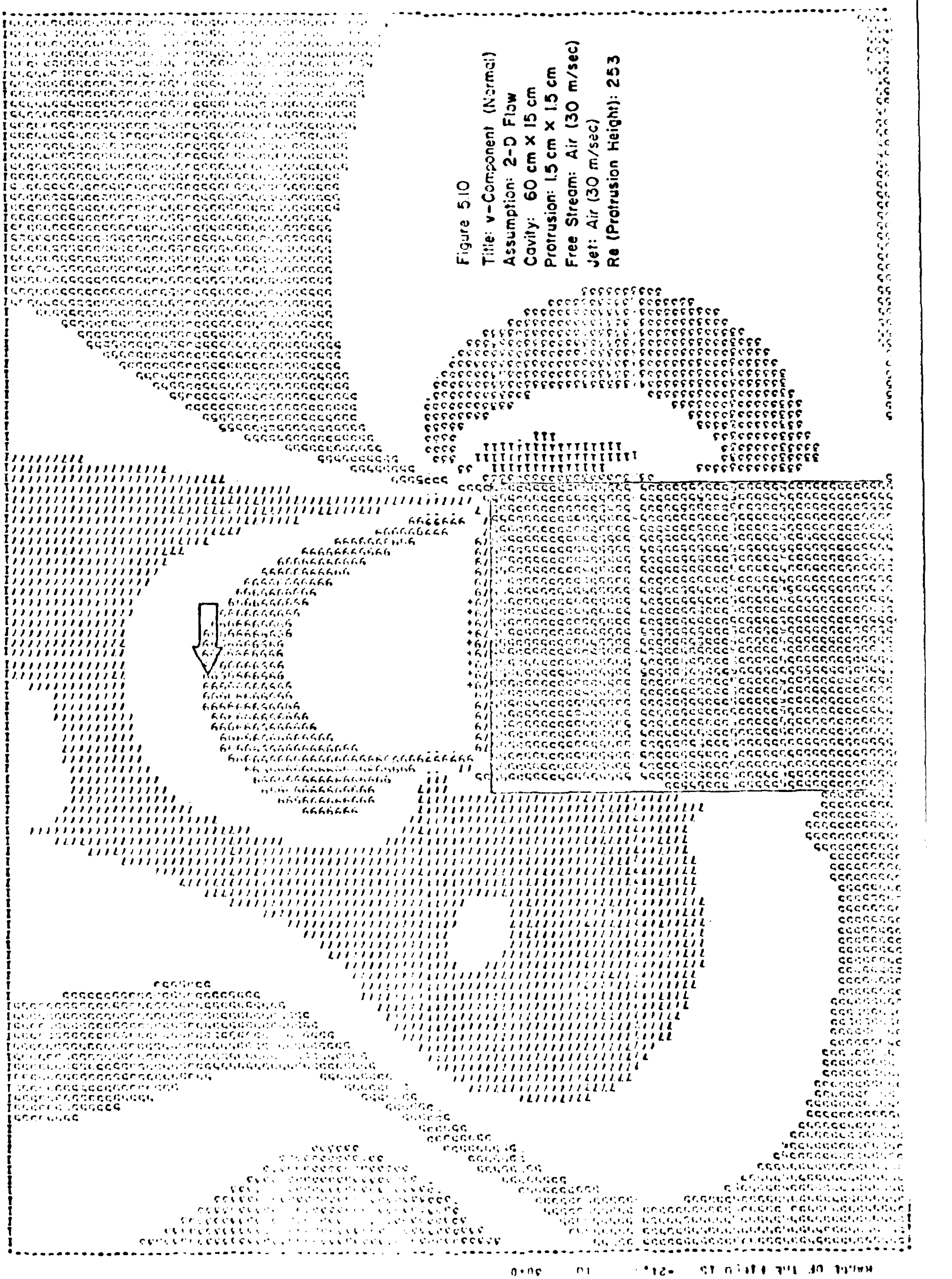


Figure 5.10
Title: v-Component (Normal)
Assumption: 2-D Flow
Cavity: 60 cm x 15 cm
Protrusion: 1.5 cm x 1.5 cm
Free Stream: Air (30 m/sec)
Jet: Air (30 m/sec)
Re (Protrusion Height): 253

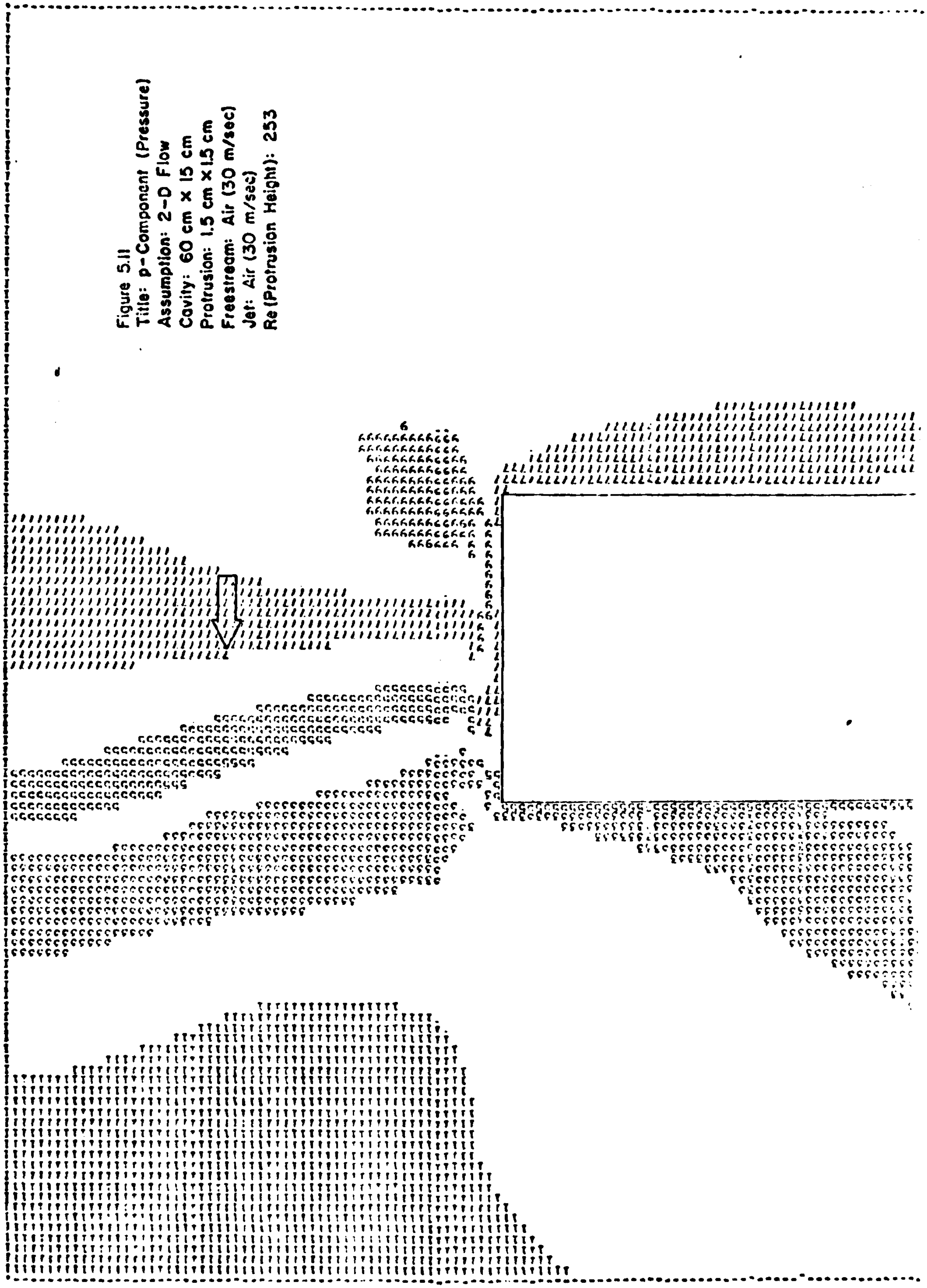


Figure 5.11
Title: p-Component (Pressure)
Assumption: 2-D Flow
Cavity: 60 cm x 15 cm
Protrusion: 1.5 cm x 1.5 cm
Freestream: Air (30 m/sec)
Jet: Air (30 m/sec)
Re (Protrusion Height): 253

END
1-87
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